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Circular No. 633

Papaya Production in the United States

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Division of Fruit and Vegetable Crops and Diseases
Bureau of Plant Industry

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UNITED STATES DEPARTMENT OF AGRICULTURE

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Papaya Production in the United States

By **Hamilton P. Traub**, *principal horticulturist*, **T. Ralph Robinson**, formerly *senior physiologist*, and **H. E. Stevens**, *senior pathologist, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry*

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INTRODUCTION

The papaya (*Carica papaya* L.) is native to tropical America, but soon after the discovery of America its culture spread rapidly along the trade routes to nearly all tropical regions. The numerous seeds produced by the fruit made its prompt dispersal easy. Although it is mainly tropical in its requirements, the merits of this early-bearing "tree melon" , which is a source of A, C, and other vitamins and of a digestive ferment similar in action to pepsin and can be eaten fresh, frozen, preserved, or pickled, are so generally recognized that, despite the hazards of frost, repeated efforts have been made to extend papaya culture to subtropical areas. In the United States the papaya has been grown in Florida for many years, and so-called "wild" plants are fairly common on the coastal keys. Recently papaya growing has been undertaken commercially in the lower Rio Grande Valley of Texas. In

California some attempts have been made to grow papayas, but production is largely limited to greenhouse-grown or otherwise specially protected plantings.

In Hawaii, the Canal Zone, Puerto Rico, the Virgin Islands, and the Philippines the papaya is commonly grown and is an important article of diet. Its culture, however, is chiefly for home use and for local markets. Recently in Hawaii efforts have been made to develop by breeding methods a uniform type of good shipping quality that could be successfully marketed in the west coast cities of the United States. This effort offers much promise provided certain precautions against the introduction of insect pests, chiefly fruitflies, can be successfully worked out.

The papaya is a semiwoody evergreen tree growing to a height of 10 to 25 feet and generally bearing few or no lateral branches unless topped. The plant as a rule is dioecious (pistillate and staminate flowers on different plants) in flowering habit, although hermaphrodite (perfect-flowered) forms are not uncommon. In the dioecious form, pollen-bearing or staminate flowers and fruit-producing or pistillate flowers are borne on different plants. In the hermaphrodite form the flowers have both pistils and stamens (fig. 1, *G*). This form is sometimes spoken of as bisexual and plants of this type are usually self-fertile or at least are capable of fruit production. Besides these main types various intersexual forms occur, with a varying proportion of staminate and pistillate flowers on a single plant. Even the typical staminate plant with a long inflorescence may occasionally produce terminal pistillate or hermaphrodite flowers, which give rise to elongated cylindrical fruits unlike the normal form of the papaya. Experience has demonstrated that these intersexual forms as well as the hermaphrodite form will not breed true, seedlings generally producing a mixture of fruiting types. This is discussed later in connection with papaya breeding (p. 4).

From the standpoint of early production in a brief period from seed, the papaya is practically unrivaled among fruits as seedlings may come into heavy production during the first year and bear several successive crops under favorable conditions. Except for the numerous hazards affecting the crop, chiefly damage from cold, wind, and excessive water, the production would soon threaten to exceed the demand, but so far, in continental United States at least, there has been no such condition. Recognition of the merits of the papaya for more general consumption has been delayed by the toleration of inferior varieties and the variation in fruit quality resulting from indiscriminate planting of seed obtained from open-pollinated fruits.

The papaya is a source of an important digestive ferment called papain, similar in its action to pepsin. This product is obtained by scarifying or bleeding the green fruit, the exuding latex being collected and dried. Practically all of the dried commercial papain is now imported into the United States. It has been a common practice in the Tropics to rub slices of green papaya over meat preparatory to cooking to render it more tender.

The ripe fruit is pulped and put up in the form of preserves or as a bottled drink. The fresh papaya is generally recognized as of value in promoting health, and its increasing popularity is partly due to this fact. It is also an excellent source of vitamin A, a good source

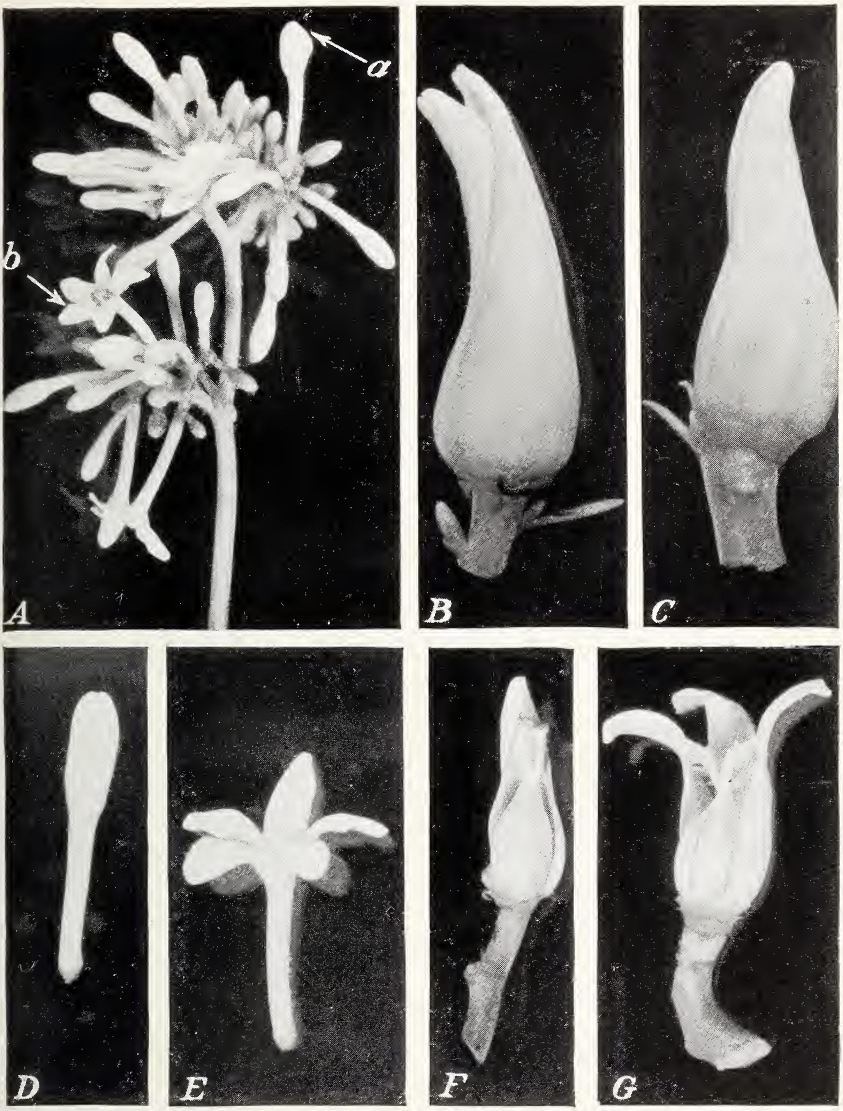

FIGURE 1.—*A*. Typical cluster of staminate papaya flowers, dioecious type: *a*, Flower ready to open, with pollen already shedding; *b*, open flower. (× about ⅘.) *B* and *C*, Typical pistillate flowers, dioecious type; *B*, flower starting to open, ready for pollination. (× about 1.) *D* and *E*, Similar to *A*, *a* and *b*, but somewhat enlarged. *F*, Pistillate flower a few days after pollination, petals on near side removed. (× about ½.) *G*, Hermaphrodite flower with stamens shorter than pistil.

of vitamin C, a fair source of vitamin G, and has an appreciable amount of vitamin B (*1, 10, 13*).[1]

The papaya is commonly eaten in much the same manner as a cantaloup. Although people often eat it plain, others like the addition of a little salt and lemon or lime juice. The fruit should be soft to the touch, but not mushy, when ready for consumption. This state is usually (though not in all varieties) characterized by a rind color change from greenish to yellow. The fruit is cut in halves lengthways, and the seeds are removed. Six or eight portions can be served from a single large fruit.

Papaya sliced or diced is frequently used in salads or fruit cocktails, combined with orange, pineapple, mango, guava, or other fruits. The ripe fruit is also utilized in various preserves, such as papaya jam and marmalade. When such cooked products are prepared some additional flavoring is usually added, such as ginger, lemon juice, or both. The ripe papaya pulp may also be served in various frozen desserts, such as sherbet and mousse, with or without the addition of other fruits or flavors (*13*).

In preparing papaya pickle, the half-ripe fruit is used. The green fruit may also be stewed or baked and served as an acceptable substitute for squash, which in the cooked form it resembles. Persons interested in preserving or otherwise utilizing papayas should consult the local county home demonstration agent for more detailed suggestions and recipes.

BREEDING AND POLLINATION

Early History

The subject of papaya breeding has recently been reviewed by Traub and Robinson (*21, pp. 44–51*). The following brief summary is abridged mainly from this source.

Because of the necessity of eliminating numerous staminate plants in the dioecious type after growing them to the flowering stage, most of the early efforts to breed improved strains of papaya were concerned with developing hermaphrodite, or perfect-flowered, fruiting varieties. Work of this character was carried on in Hawaii by Pope, Higgins, and Holt, and later by Storey and Michener; in the Philippines, first by Wester and later by Torres, DeLeon, and Galang. In Florida, Stambaugh has likewise specialized on the hermaphrodite type of papaya in his selections. Most of these so-called hermaphrodite forms were found to segregate profusely in the direction of the dioecious form and various intermediates, with corresponding variability in fruit shape, size, and quality. Hofmeyr (*5*) in South Africa has adopted sib pollination (crossing of dioecious plants having the same parentage) as a means of inbreeding papayas but has likewise striven for the ultimate development of hermaphrodite varieties.

In the breeding work of the authors the fact that the hermaphrodite type is permanently heterozyous has been recognized, and emphasis has been placed on inbreeding selected dioecious types through sib pollination. The details of this work, together with the results of more recent breeding work in Hawaii by Storey (*15*) and Michener (*9*) are discussed later (p. 9).

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[1] Italic numbers in parentheses refer to Literature Cited, p. 35.

OBJECTIVES

For utilization in the subtropical areas of the United States, the ideal papaya should meet certain requirements. For the fresh fruit trade: 1, It should be relatively small, 2 to 3 pounds or even smaller (large fruits may be utilized in the preserving industry); 2, the flesh should be not less than three-quarters of an inch in thickness; 3, the rind should be firm and show a color change from green to yellow upon ripening; 4, the fruit should be slow ripening, i. e., remaining edible at ordinary temperatures for a week or more after picking, as determined by the latex test (*22*); 5, the flavor and aroma should be pleasing, medium sweet, mildly "cressy," and free from the musky flavor of some of the wild strains; and 6, the plant should be stocky and precocious, coming into flower within 2 to 3 months, fruiting within 9 months from seed, and setting fruit within 2 to 3 feet of the ground. These fruit and plant characters have been sought in breeding work, and the progenies of each generation have been examined (*9*), are discussed later (p. 9).

POLLINATION

The most active pollen-transferring agents are the so-called sphinx or hummingbird moths. These moths, belonging to the family Sphingidae, are most active in the early morning and during the twilight hours of evening, resembling small hummingbirds in their darting flights from flower to flower. With their long proboscis they are especially adapted to obtain nectar from staminate flowers having a long corolla like that of the papaya. In their larval forms they are known as hornworms [*Erinnyis alope* (Drury) and *E. ello* (Linn.)] and sometimes cause damage by eating papaya leaves.

Experiments with papaya flowers[2] (*19*, *20*) have shown that, although they are receptive to pollination for several days after opening, the best results of hand-pollination are obtained soon after flower opening; also, that it takes up to 5 days for the pollen tubes to reach all of the ovules, including those at the base or stem end of the fruit—the first requisite for seed formation and good fruit quality of the whole fruit. When insufficient pollen reaches the stigma or when pollen-tube growth is from any cause interrupted, seeds will form only in a portion of the seed cavity, at the apex or pistillate end. This portion of the fruit is usually somewhat larger, sweeter, and better flavored than the portion devoid of seeds (fig. 2).

The course of pollen-tube growth after passing from the stigmatic surface downward through the central region of the style is mainly on the surface of the central cavity (*20*). In the case of open-pollinated flowers, there is nothing in the mechanism of ovule fertilization to prevent pollen derived from two or more males from functioning in seed formation in the same fruit. Therefore, it is not surprising that through mass selection from open-pollinated fruits little progress has been made towards fixing desirable papaya varieties.

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[2] TRAUB, H. P., and O'RORK, C. T., JR. PAPAYA POLLEN GERMINATION AND STORAGE; RATE OF POLLEN TUBE GROWTH AND DURATION OF PISTIL RECEPTIVITY. [Unpublished manuscript.]

Storage experiments with papaya pollen have shown that under proper conditions of temperature and humidity (approximately 34° F. and 10 percent relative humidity) papaya pollen may be stored for a period of more than 6 months and retain a fair degree of viability[3] (*19*).

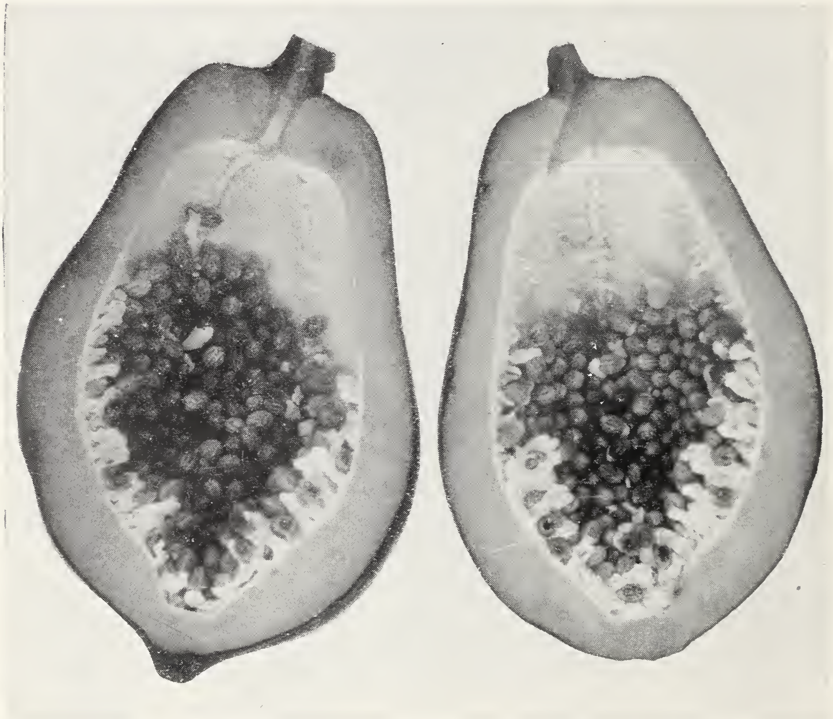

FIGURE 2.—Fruit of open-pollinated *Carica papaya*, showing failure to set seed in basal end and its effect on pericarp development; portion lacking seeds not fully developed and generally of poor quality.

SIB POLLINATION IN DIOECIOUS TYPES

The procedure for sib pollination and consequent line breeding of dioecious types of papaya requires no elaborate technique or special training and is easily practiced by any fruit grower. Seedlings of each variety should be planted in separate blocks and an accurate plat made of the planting. Three seedlings are usually planted in a hill to obtain a sufficient stand of pistillate plants. As the plants come into flower, the excess staminate and pistillate ones may be removed, saving about 2 staminate to 15 pistillate plants. The flowers of the pistillate plant are large and are usually borne singly (or with occasional branching) on short stems in the avil of the leaf (fig. 1, *B* and *C*). A little observation will soon enable one to judge when these flowers are about ready to open. A small brown-paper bag (4-ounce size) should be placed over the flower at this stage and fastened with a rubber band or paper clip to prevent chance pollination. If more than 1 flower occur, only the larger central flower should be used for pollination, any side flowers being cut off.

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[3] See footnote 2.

A day or two later, when the bagged flower begins to open, an unopened mature staminate flower of the same variety (fig. 1, *D*) is taken when its anthers are discharging pollen, the petals are removed, and this flower is used to lightly dust with pollen the stigma, or "crown," of the pistillate flower (fig. 3, *A*). The individual staminate flowers are small and are borne in clusters on long branches, which often reach a length of 2 to 4 feet (fig. 4, *B*). Observation and testing by tapping the anthers against the thumbnail will readily show whether one of these flowers is shedding pollen, a yellowish powder. To apply the pollen thoroughly, it will often be necessary to force open the end of the partially opened pistillate flower by giving the stiff petals a slight twist. After the pollen has been supplied to the stigma of the pistillate flower, the bag should be replaced, the flower well tagged, and the bag left in place for 7 to 10 days to guard against other pollen's reaching the stigma

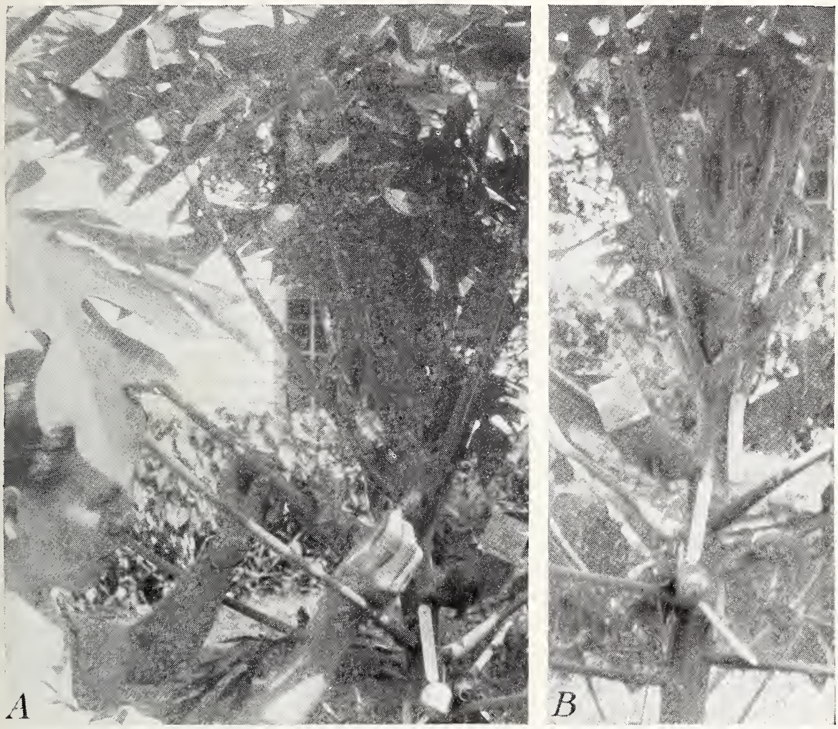

Figure 3.—Hand-pollination: *A*, Breeder holding staminate flower with petals removed and pollen-bearing stamens exposed, and dusting stigma of pistillate flower with pollen; at right of operator's hand is shown flower covered by bag to prevent chance pollination; bags are replaced after pollination. *B*, Fruits already set and tagged, and bags protecting flowers that are nearly receptive.

(fig. 3). Such tagged fruits should be conspicuously labeled with dates recorded in a record book, and, when the fruits are ripe, they should be saved for seed. As a single fruit often has upwards of 1,000 seeds, a few such hand-pollinations will usually suffice for the average grower's needs. To maintain the elite line, this same procedure must be repeated during successive generations, each year using staminate and pistillate individuals for pollination from the same generation of the inbred or elite line.

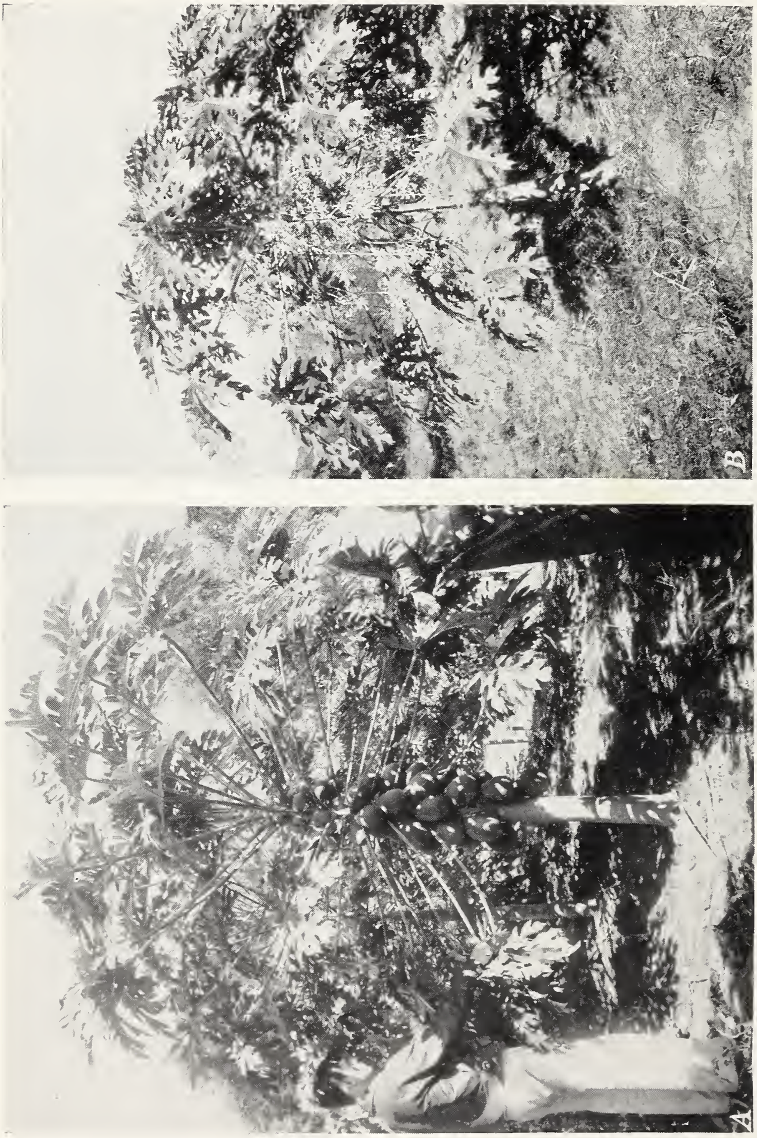

FIGURE 4.—*A*, Fairchild (No. 745) papaya plant 10 months from seed. *B*, Typical staminate plant (Betty variety) with long branched panicles; plant grown as a second-year sprout rejuvenated from an old root system.

SELF-POLLINATION IN HERMAPHRODITE TYPES

The breeding technique thus far considered has reference to the dioecious types that usually produce from seed an equal number of staminate and pistillate plants. Because of the necessity of discarding a large number of pistillate and staminate plants after they have grown to the flowering stage in plant boxes, there have been many attempts to develop hermaphrodite or self-fertile varieties. The failure to obtain such stabilized varieties from self-pollinated hermaphrodite parents can now be understood in the light of investigations by Storey (*15*) and Michener (*9*) in Hawaii and Hofmeyr (*5*) in South Africa.

Under carefully controlled conditions the desired hermaphrodite form (type IV) of the Solo variety has been obtained in approximately two-thirds of the seedlings produced in the third generation, but there was no further increase (*9*, *15*). Nearly all of the remaining third proved to be pistillate individuals. Thus hermaphrodite, pistillate, and staminate individuals were obtained, respectively, in a 65–34–1 ratio, on self-pollination. The pistillate plants bore fruits differing in shape and quality from the hermaphrodite form, which would indicate that fruit shape and quality, at least in the Solo variety, are sex-linked.

INHERITANCE IN PAPAYA

Storey (*16*) has distinguished 5 floral types in the papaya: 1 purely pistillate, 3 hermaphrodite, and 1 purely staminate. These are further designation as type I, pistillate form; type II (often referred to as the "pentandria"), from hermaphroditic modification of type I, having 5 carpels and 5 stamens, fruits deeply lobed; type III, an intermediate form between types II and IV, having from 2 to 10 stamens, pistils frequently distorted and developing misshapen fruits; type IV, sometimes referred to as "elongata," hermaphrodite form having 10 stamens arranged in double series to form a cylinder that encloses the greater portion of the pistil, fruits varying from long cylindrical to ellipsoid with more or less bulbous base (this type is considered desirable for commercial propagation, despite the fact that only about two-thirds of the seedlings from self-pollinated individuals are true to type of plant and fruit); type V, typical staminate form, flowers slender and borne in much-branched panicles in contrast to the short-stalked flowers of the other types. These types are also described by Wolfe and Lynch (*23*).

Michener (*9*) has further studied the genetics of the papaya in Hawaii. Using the classification adopted by Storey, he found that the proportion of pistilloid (deformed) fruits on hermaphrodite plants may fall anywhere between 0 and 100 percent, although one or another of the five types often predominates. He found it impossible to detect any simple Mendelian segregation; also that hermaphrodite trees, especially those having no pistilloid fruits, have the characteristic of forming sterile flowers during the late summer and fall, with a resulting lack of fruit production. Pistilloid fruits (in which stamens become carpels and unite, often imperfectly, with the pistils) comprise types II and III described above and are not considered desirable forms.

Hofmeyr (*5*) has reported the results of genetic studies of the papaya in South Africa particularly with reference to the inheritance of sex and its relation to certain plant characteristics and sex reversal and sex forms. Among the conclusions of importance to growers, the following are noteworthy. No relation was found between vigor and sex, so that the sex of young seedlings cannot be determined in this manner. Purple stem is dominant over nonpurple in crosses, and yellow over red flesh, but these characteristics show no linking with sex. Crossing of pistillate and hermaphrodite individuals offers a means to eliminate unproductive (staminate) trees in the grove. Such crosses give 100 percent of fruit-bearing trees, 50 percent of which will usually be hermaphroditic.

The main objection to fruit of hermaphrodite trees is the irregularity in shape of fruit (as noted by Michener (*9*) in Hawaii). Because of their dissimilarity, it is suggested that fruit from hermaphrodite and pistillate trees be put on the market under different brands. Experiments to induce sex reversal, as by removal of the terminal bud and other means, gave negative results. However, a common type of partial sex reversal is that of a staminate individual that produces a few hermaphroditic flowers, but this does not represent a genetic change. Michener makes reference to no named or inbred varieties used in his breeding work.

The Solo variety, grown from selected Hawaiian seeds, as tested in Florida by the writers, has thus far proved poorly adapted on account of its habit of late flowering, often producing a trunk 8 to 10 feet tall before the flowers appear and the fruits begin to set. Thus it may take 18 months from seed planting before fruits begin to mature. Other so-called hermaphrodite varieties of better fruiting habit have been successfully grown in Florida and in the southern part of Texas—notably by Stambaugh (*12*)—but stability as to shape and size of fruit has not been obtained, doubtless because of a segregation of sex types similar to that found in the Solo variety in Hawaii.

For the amateur breeder, attention should be called to the fact that, in many of the hermaphrodite forms observed in Florida, the stamens at the base of the pistil are so short that self-pollination is in most cases unlikely to occur, the anthers being often an inch below the stigma when the latter becomes receptive. With such floral types, pollination (except when done by hand) in most cases must be dependent on pollen brought from other plants, either from pure staminates or from hermaphrodites. That cross-pollination is usually necessary for such hermaphrodite forms is evidenced by the fact that when flowers of this character are bagged to prevent cross-pollination occasionally fruits will develop to maturity but will be entirely devoid of seeds. Such parthenocarpic fruits are usually of inferior quality. Furthermore, some of these hermaphrodite forms have proved sterile to their own pollen even when hand-pollinated.

INTERSPECIFIC HYBRIDIZATION

Several species of *Carica* are decidedly hardy as compared with the common papaya. One of these, often referred to as the mountain papaya (*Carica candamarcensis* Hook. fil.), grows at an elevation of 8,000 to 9,000 feet in Colombia and Ecuador and will stand several

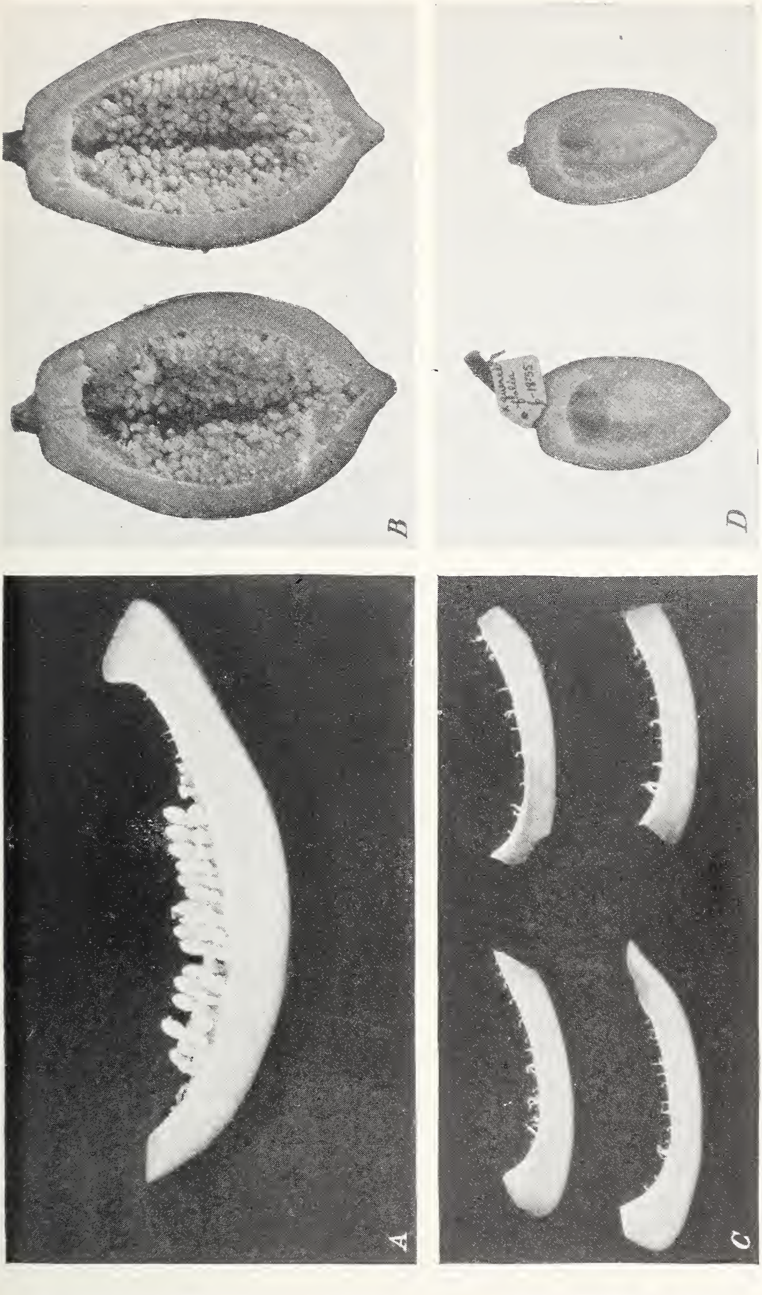

FIGURE 5.—*A* and *B*, Open-pollinated fruit of *Carica papaya* (control). *C* and *D*, Fruit from *Carica papaya* ♀ × *C. quercifolia* ♂ on same plant. Note that this fruit is small and seedless except for abortive seeds reaching partial development after pollination.

degrees below freezing without injury. The fruits, however, are small and are chiefly utilized in stewed form. Attempts by the writers to obtain hybrids between this species and *C. papaya* have thus far failed, as have also attempted crosses with other semihardy species, such as *C. quercifolia* (St. Hil.) Solms (fig. 5) and *C. hastae-*

folia Solms. Higgins and Holt (*4*), in 1914, reported failure in their efforts to obtain hybrids between *C. papaya* and *C. quercifolia* but did succeed in hybridizing *C. papaya* and *C. gracilis* (Reg.) Solms. In Jamaica, at the Hope Gardens, crosses between *C. papaya* and *C. cauliflora* Jacq. have been reported by L. N. H. Larter, Government Botanist (*21*).

Further work in breeding papayas of greater hardiness is in progress, but the results cannot be predicted with any degree of certainty. As some of the semihardy species exhibit resistance to certain papaya diseases, their use in hybridization might serve a double purpose. It is probable that knowledge gained from pollen-germination studies now in progress may increase the chances for success in interspecific hybridization work (*19*, *20*) for pollen may be stored for use when needed.

Hardiness of Staminate and Pistillate Plants

The relative hardiness of staminate and pistillate papaya plants as sex-linked characters is sometimes a matter of speculation, claims occasionally being made that the staminate is more cold resistant. A census of 3 lots of seedlings made in December 1935 after a mild freeze (minimum temperature 28° F.) at Orlando, Fla., showed no conclusive differences between the staminate and pistillate plants. Although the numbers involved were not large they are believed to be fairly representative. Of 50 staminate plants 30, or 60 percent, were apparently uninjured. Of 42 pistillate plants 30, or 71 percent, were killed; 11, or 27 percent, injured; 1, or 2 percent, apparently uninjured. On a percentage basis the advantage is with the staminate plants, but with the use of larger numbers this advantage might not hold. At any rate such results need to be checked.

STANDARDIZATION OF VARIETIES

The progenies under test by the writers for a number of seasons, 30 in all, were critically examined and data recorded as to height and diameter of stem, spread of leaves, height of basal fruits, yield, single or branched fruit pedicels, leaf type, and color of flowers and of leaf petioles. The fruits when ripe were tested for taste, quality, and other important characteristics, such as size, weight, and shape of fruits, thickness of flesh, size of cavity, color of rind and pulp, firmness of rind and flesh at the ripe stage (determined by the standard pressure test), seed content, character of seed, and placental attachment. In describing taste qualities, several categories such as the following were adopted to include the wide range of flavors and odors found in this fruit type: Predominant flavor, cressy (slight, medium, or strong) or sweet (slight, medium, or decided); predominant aroma, papaya or other, as musky, pumpkin, etc. (slight, medium, or strong). Other flavors, as bland or insipid, may be occasionally encountered. Persons just becoming acquainted with the fruit of the papaya sometimes prefer the bland-flavored sorts, fairly sweet, to the more typical medium cressy, medium sweet, with pleasant papaya aroma.

Seeds from inbred (sib-pollinated) or crossbred fruits were carefully washed and dried, labeled, and stored for future use. Progeny blocks of each selection meriting further propagation were planted. Out of the 30 progenies under test, it has been found possible to make selection of 3 varieties of sufficient merit and uniformity to justify their distribution. Fairchild (No. 745) (figs. 4, *A;* 6) was sent out in the 1938 season in a limited way to cooperators for trial in commercial plantings, and Kissimmee (No. 758) was sent out in 1939. Germination tests have been made of the various lots of seed to determine whether continued inbreeding affects adversely the germination percentage and the vigor of young seedlings. Likewise, pollen viability of sib-pollinated lines has been tested to discover whether periodic crossing with other inbred lines may be necessary to maintain viability and vigor. Already evidence points to the probability that some such procedure may be found desirable or necessary.

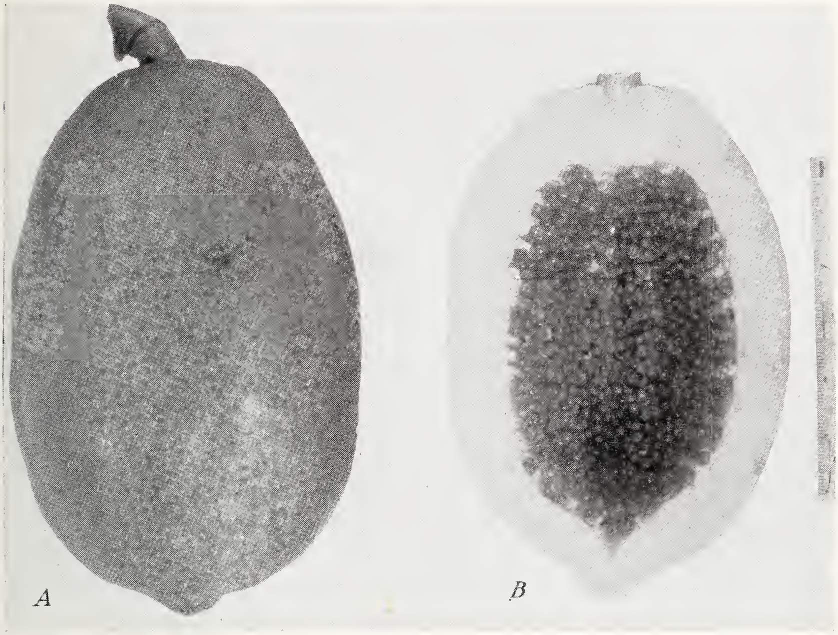

FIGURE 6.—Fairchild papaya, typical fruit of selected inbred strain No. 745: *A*, Exterior; *B*, interior. (× about ⅓.)

During the season 1939–40, the cross of two inbred lines, Orlando ♀ (No. 706) × Fairchild ♂ (No. 745), gave more vigorous progeny than that from selfed parents. The summer was unusually dry, but most of the progeny from this cross produced good crops, whereas the parent lines set fruit very poorly under the same growing conditions where no irrigation was given.

DESCRIPTION OF VARIETIES

Relatively few papaya varieties have been introduced, and nearly all plantings are still grown from seeds obtained by open pollination. This lack of uniformity and quality has been one of the chief handicaps of the industry. The following list of varieties at least shows that a beginning has been made toward overcoming this handicap, and the introduction of other important varieties is certain to follow.

FAIRCHILD (No. 745)

Fairchild (No. 745), introduced by the United States Department of Agriculture in 1938, was named for Dr. David Fairchild, who, among his numerous plant introductions, included some of the most promising strains of papaya (figs. 4, *A*; 6). The present variety, of the dioecious type, has been developed by selection and subsequent sib pollination, the parent lot of seeds being from open pollinations of a local strain of unknown parentage. Fruits of the selected parent individual were notable for the firmness of the rind and flesh combined with good eating quality and attractive yellow color. Sib pollinations have been carried on for only four seasons, but substantial uniformity was attained in the progeny of the 1939–40 crops.

A typical fruit of the Fairchild variety (fig. 6) weighs about 4 pounds, is rounded-oblong in shape, 8 to 9 inches long by 5 to 6 inches wide, yellowish when well ripened, smooth or slightly ribbed. The fruits are borne fairly low on the stem (basal ones 2 to 3 feet from the ground), on short stout pedicels, singly as a rule, the pedicels being long enough (3 to 5 inches) so that the fruits are not badly crowded on the main stem of the plant. The fleshy portion is thick (7/8 to 1 1/8 inches), making a firm fruit with a large edible portion. Pressure tests of the rind of ripe fruit give a resistance of approximately 10 pounds. The holding quality after picking as determined by the latex test, i. e., when the latex exuded from pricked rind is watery rather than milky (*23*), is especially good, fruits ripening slowly (6 to 12 days at room temperature) and remaining in edible condition for several days after softening. Fruit on the tree usually ripens in about 5 months from the date when the flower is pollinated and fruit set, and ripening proceeds fairly well even in the cool winter months, a feature of much importance. A well-seeded fruit contains about 1,000 seeds, which are mottled brown in color and have a dry weight of 2.6 gm. per 100. Thus an ounce of seed contains over 1,000 seeds.

The flavor is medium cressy combined with a desirable degree of sweetness having no suggestion of the strong or musky flavor and aroma present in many strains of papaya. The pulp is an attractive orange yellow and of smooth texture. The plant (fig. 4, *A*) is notable for vigor and appreciably more cold resistant than most other varieties tested in comparison, although it cannot be classed as hardy.

GRAHAM

The best variety for the low Rio Grande Valley of Texas is Graham, which was introduced by the United States Department of Agriculture in 1938. It is dioecious and produces small to medium-sized fruit of desirable shape and of excellent quality (*3*).

KISSIMMEE (No. 758)

Another variety of the dioecious type, introduced by the United States Department of Agriculture in 1939, has been named the Kissimmee. The original seeds from open-pollinated fruits, and therefore of mixed parentage, were supplied by a cooperator and were said to have been obtained from Cuba where the strain was known as an Ethiopian variety.

Typical fruits of this variety weigh from 3 to 3½ pounds, are oval, long-pointed, slightly ribbed; rind yellow with greenish dots, firm (with a pressure test of 9 to 10 pounds), and of good appearance. The pulp is deep yellow, of good thickness (1 to 1¼ inches), and of excellent quality, sweet, medium cressy without the musky flavor or aroma often objectionable in otherwise desirable papayas. These seeds are black and numerous, there being 1,200 to 1,400 in a single well-seeded fruit. The fruits are borne on short to moderately long pedicels (3 to 4 inches), usually singly. The fruit ripens in 4 to 6 days after picking as determined by the latex test and is notable for its ability to ripen through the cool months of the Florida winter, when ripening of many papaya varieties is arrested.

BETTY

One of the favorite varieties in Florida plantings is the Betty, a dioecious type, developed by Bronson Bayliss, of Miami. His first selection was made from a cross of a pistillate individual, obtained from seeds supplied by the United States Department of Agriculture, with a male from another source. By successive sib pollinations through a number of years the type has been fairly well fixed. The Betty variety is characterized by a semidwarf to medium-sized tree as grown under Florida conditions, which affords a degree of immunity from wind damage. The plant starts flowering within 2 to 3 months from seed, thus permitting prompt elimination of excess staminate plants. The basal fruits are usually produced within 18 to 24 inches from the ground. The fruits are rounded-oblong, 2 to 3 pounds in weight; flesh fairly thick (about three-fourths of an inch); rind and pulp rather soft; dessert quality excellent. Its chief defect is its lack of shipping and keeping quality, but for local markets and home consumption it has distinct merit. Its fruiting habit is also an asset that may be utilized in appropriate crosses with types having a firmer flesh and rind.

SOLO

The Solo variety, of the hermaphrodite type, which segregates in the ratio of 65–34–1 hermaphrodite, pistillate, and staminate plants, respectively, has long been a favorite in Hawaii and the Canal Zone. Under tropical conditions it produces a tall slender plant with an abundance of small fruits, 10 to 16 ounces in weight. Both round and pear-shaped fruits are produced and the ripe fruit is smooth, bright yellow to orange in color, sweet and cresslike in flavor. Under Florida conditions the Solo is slow to come into bearing, sometimes failing to flower until 12 to 18 months old, and the fruit, while of excellent eating quality, does not color well and is variable in shape. Its small size and good quality may be utilized in appropriate crosses to secure a variety better suited to Florida conditions.

Blue Stem

The Blue Stem variety, so named from the fact that the leaf petioles and fruit pedicels are bluish lavender or purple, is of the hermaphrodite type (*12*) and has been one of the popular varieties in Florida for the past 10 years. Although generally spoken of as bisexual (hermaphrodite) such a variety segregates in the ratio of 65–34–1 hermaphrodite, pistillate, and staminate plants, respectively, as does the Solo variety.

The fruit generally is large, 4 to 8 pounds in weight, long-oblong or tapering at the stem end, more or less ribbed especially at the blossom end, which commonly is more or less enlarged. This fruit is often classed as elongata. The rind is somewhat rough, dark green, showing slight yellowing as maturity approaches. The keeping quality is fair to good. The flesh is thick and meaty, 1 to 1½ inches in thickness, of excellent flavor and of attractive orange-yellow color.

For local markets and home use, this large fruit is not objectionable and for preserving may be preferable to the small-fruited varieties. The plant is a vigorous grower, making a tall plant and bearing most of its fruit crop from 4 to 8 feet from the ground.

PROPAGATION AND PLANTING

The papaya normally produces seeds in such abundance that commercial propagation should offer little difficulty once superior inbred lines are available. Although vegetative propagation by the grafting of young seedlings or rooting of cuttings has been demonstrated as possible (*2*, *18*), these methods have never proved feasible for large-scale plantings. The most economical method of propagation still is by means of seeds, and the details of this procedure will be given most consideration in this circular.

Seed Propagation

PREPARATION AND STORAGE OF SEEDS

Where seeds are to be saved for future planting, some precautions are necessary to avoid loss of viability. The freshly extracted seeds should be washed in a strainer under a stream of water and spread out on towels or towel paper. They should be gently rolled with the palm of the hand to remove any pulp clinging to the seeds that will adhere to the towel or paper. When the seeds have thus been cleaned and excess moisture has been removed, they should be spread out thinly on improvised paper trays, such as newspapers with edges folded inward. Seeds should be thoroughly air-dried and drying should be done in the shade but not to the point where the seeds become very hard and brittle.

The thoroughly air-dried seeds should be stored in airtight containers, such as quart-size jars with rubber gaskets. To prevent possible molding or insect infestation, a small quantity of copper lime dust (20 percent of powdered copper sulfate and 80 percent of hydrated lime) should be mixed with the seeds in the jar. This dust is obtainable at most seed stores. Seed should be stored in a comparatively cool dark place.

PLANTING SEEDS AND RAISING PLANTS

For spring planting, seeds may be sown in coldframes, flats, or boxes during January or February, providing they can be effectively protected against cold injury. If such protection is not feasible, planting should be deferred until after danger of killing frost. The vital temperature for papaya, the temperature above which growth occurs, is higher than that for citrus for which it is 55° F.; and as seeds will not germinate in cold soils, seed flats should be kept in a warm place until plants are well started. The soil used for starting seeds should be heat-sterilized for protection against loss through damping-off and nematode infestation. A mixture of equal parts of well-rotted manure, loam, and coarse sand makes a good starting medium. Seeds are usually planted three-fourths of an inch deep in shallow drills.

Transplanting is often done by setting individual plants in 4-inch paper pots or by using flats divided into 3- or 4-inch squares by paper plant bands. If larger containers, as 6- by 6- by 6-inch boxes or quart tin cans, are used, 2 or 3 plants should be set in each container (fig. 7). It is usually worth while to use these large containers to allow for the development of an adequate root system before transplanting to the field. Plants should never be so crowded in seedbed or flats as to become spindly. When the plants average 8 to 10 inches high, they may safely be set out in the field. With varieties of dioecious character, 3 plants should be set in each hill to insure the required percentage of pistillate plants in the final stand. After flowering starts, the excess pistillate and staminate plants may be removed, leaving about 2 staminate to 15 pistillate plants. Although shading is usually desirable for small plants recently set out, they should be given full sunlight as soon as well established.

Late-summer planting in some sections has certain advantages despite the risk of winter injury, if plants become well established before cool weather sets in. When cold threatens, mounding the bases for 6 to 8 inches will usually prevent complete loss of plants, but the mounds should not be left in place, especially if warm, moist weather follows. If a good root system is obtained, the plants may be cut back in the early spring to about 12 inches from the base (whether cold-injured or not) and the plant will usually send out vigorous new sprouts. After a few weeks these sprouts should be thinned to one strong sprout, which, because of its rapid development, will usually be in full fruit by early winter. One common difficulty experienced with papaya growing is the tendency for fruits from small plants set in March or April to have their development checked by cool fall and winter weather and shortened length of day, with the result that they either fail to ripen for many months or do not develop a normal sugar content and are disappointing in flavor. Lynch and Fifield (7), using as material the Betty papaya, have recently shown that the sugar content (reducing substances) is the main factor differentiating pleasant-tasting papayas from flat-tasting ones. It was shown that a lowering of the reducing-sugar content by 2 or 3 percentage units from the normal is sufficient to render the fruit unsatisfactory. If the late-summer or fall setting is lost from cold or other causes, there is still a chance to reset in the spring.

RELATION OF SEX RATIO TO PLANTING PRACTICE

When planting is limited to a few dooryard trees, disappointment is often experienced in having most of the trees prove to be staminate. At present there is no known method of overcoming this difficulty. Experiments by the writers and others as to the effect of the position of seeds in the fruit on the sex of seedlings have given negative results. Careful check on the sex ratios in strains of dioecious varieties purified by selection within sib-pollinated lines has shown the normal expectancy of 50 percent of each sex form in a population of sufficient size, 100 plants or more. The recommendation to set 3 plants in a hill in order to obtain the required stand of female plants is based on these results.

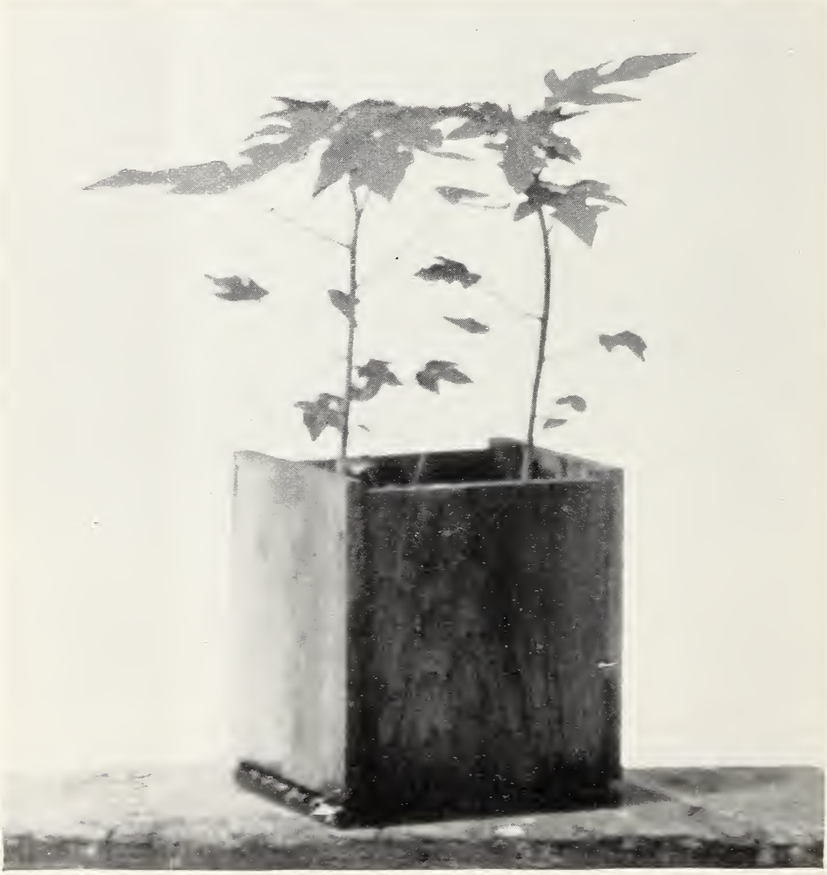

FIGURE 7.—Plant box with two papaya plants at stage suitable for transplanting to one hill in the field. With a dioecious inbred variety, 70 to 80 percent of hills so planted will furnish at least one pistillate plant.

VEGETATIVE PROPAGATION

For the preservation and multiplication of valuable individual plants, especially in the course of breeding experiments, it is often desirable to resort to vegetative propagation. For dooryard or home-garden plantings, also, such vegetatively propagated plants have a distinct value, insuring the sex of the plant and the character of the product.

A mature plant having no side branches may be topped and thus forced to produce side shoots suitable for use as cuttings. Sometimes a few side shoots are produced without cutting back the parent stock. When the shoots are about 1 inch in diameter, they should be carefully cut from the stem, and the cutting should include a heel or the basal swelling. The larger leaves, if any, should be removed or cut back, leaving intact the smaller terminal leaves on the cutting. Shoots a foot or more in length may be divided into cuttings approximately 6 inches in length. In this case the cuttings should be made before leaf removal, and finally at least one leaf should be left on the upper portion of each cutting. However, unless one has excellent propagating equipment, with bottom heat and control of humidity, the shoots should be left intact. A mixture of equal portions of coarse sand and pulverized peat or similar material provides a suitable medium for the propagating bed. This bed should be 6 to 8 inches in depth and well drained. Drainage may be provided either by a layer of broken stone at the base or by having the bed raised from the ground and provided with coarse ¼-inch mesh wire netting bottom, well supported by slats. The wire netting should be covered with a thin layer of moss to hold the sand-peat mixture in place.

ROOTING WITH BOTTOM HEAT

For the best results some form of bottom heat should be provided either by the use of a solar propagating frame (*17*) or by some source of artificial heat insuring a temperature of 85° to 90° F. in the rooting bed (*18*). The solar frame consists essentially of a raised bed covered with a glass sash and having below the bed an enclosed space with extra glass sash placed with a southern exposure and inclined so as to admit the sun's rays. The base holds the heat thus entrapped. The sash covering the rooting bed should be shaded by a covering of muslin or similar material. In the warm summer months bottom heat is not so essential and fair success in rooting is occasionally obtained with cuttings placed in boxes or flats kept well watered and shaded. From 1 to 3 months is usually required to complete the rooting process.

ROOTING WITH HORMONES

Experiments by Traub and Marshall (*18*) have shown that synthetic indole-3-acetic acid in a dilution of 1–10,000 speeded up root formation and increased the percentage of rooted cuttings in papaya. The rooting process may thus be hastened and the percentage of cuttings rooted may be increased by the use of this substance or some of the other root-forming hormones recently put on the market, such as naphthalene acetic acid or naphthalene acetamide. These hormone preparations are available at seed stores in both liquid and powder form. Directions for their use should be followed carefully, especially in the case of liquid preparations, as injury may follow treatment of cuttings with insufficiently diluted solutions. The powder preparations are less likely to give trouble of this kind.

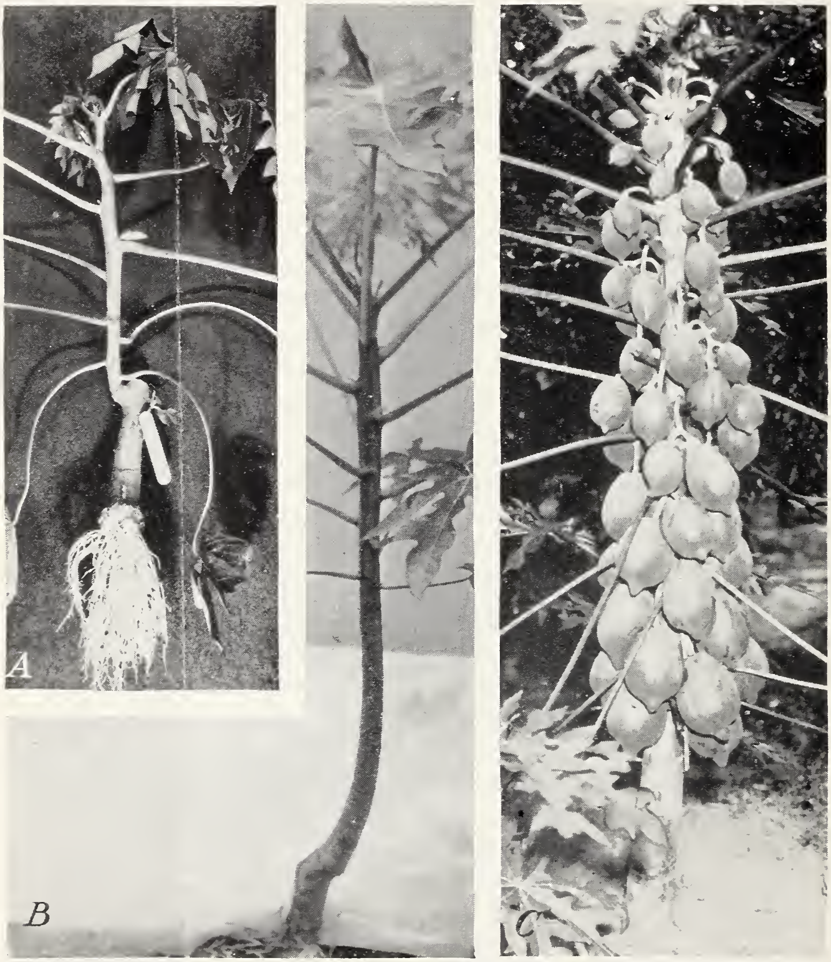

FIGURE 8.—*A*, Papaya rooted cutting showing growth made during 1 month after rooting began; *B*, 1 month later, base healed over and sprout beginning to straighten; *C*, 3 months later, with good set of fruit approaching maturity and practically straight stem.

When examination reveals that roots are developed to a length of several inches, the cuttings may be transplanted to a permanent place if the growing conditions are good, or set in cans or boxes until conditions are favorable. When first taken from the rooting bed they should be shaded, the shade being gradually reduced until they are accommodated to full sunlight. Cuttings from the proximal portion of a branch will grow into a straight trunk (fig. 8), as reported by Traub and Marshall (*18*).

Rejuvenation of Papaya Trees

Although papaya trees under subtropical conditions continue in good production more than two seasons when the winters are so mild as to cause no injury to the tree, it is desirable to consider rejuvenation as a means to insure uniformity of size and proper height in aging plants. If the root system is still healthy, as evidenced by vigorous top growth, such trees may be rejuvenated by the simple process of cutting back and growing a new stem. The trunk should be cut off cleanly at a height of 12 to 18 inches, making a slanting cut so that the stem will not hold water. These stumps should be examined from time to time, and any pockets where water might accumulate and cause decay should be drained. This cutting should usually be done in the early spring after danger of killing frost is past. The sprouts that start from the old stump should be left intact for 3 or 4 weeks; then the strongest sprout should be selected and all the remaining sprouts removed. The selected new stem should be tied to a stake to protect it from wind injury, and the stump above the sprout should be carefully cut back to within an inch or two of the base of the sprout. When the sprout is well established and growing rapidly, the stump may be finally cut back fairly close to the base of the sprout. In a few months a covering of callus tissue will be formed over the cut surface of the old stump. The cut surface of old stumps does not heal over by the meeting of new tissue from opposite sides as in more woody fruit trees, but a new cambium layer is formed from parenchymatous tissue below the callus. The rejuvenated sprouts reach the fruiting stage a month or more before young seedlings of the current season's planting. This practice may be kept up with desirable plants for a number of years, depending largely on the condition of the root system. At the first rejuvenation the new shoot will usually make an almost straight trunk, but, as the tree ages more and more, the new trunk will form at an angle to the old stump.

AN EXPERIMENT IN PAPAYA FERTILIZATION[4]

Object, Materials, and Methods

In an attempt to arrive at some rational basis for fertilizing papayas, experiments were planned and carried out in Florida during the seasons 1934–37. In connection with the hazards of papaya growing already referred to, it may be worthy of note that the experiment herein reported, carried out in 1936–37 in Manatee County, was one of four planned to obtain data on the nutrition of the papaya tree. One of these plantings, made in 1934, was lost by a freeze although located in a relatively warm area in Lee County; one, in 1935, in Lee County, was destroyed by a hurricane; and another, in 1937, in Manatee County, was lost through lack of adequate drainage following heavy rainfall. Although three of the experiments were not completed, the results corroborate those from the complete experiment.

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[4] Soil analyses, as well as determinations of sugars of fruits and mineral contents of fruits, leaves, and twigs, were made by A. E. Hughes, formerly agent, Bureau of Plant Industry, who was associated with the writers in this work from 1936 to 1938; G. M. Bahrt, associate soil technologist, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, made the soil surveys.

The complete experiment was carried out in 1936–37 in Manatee County. The experimental planting occupied about one-half of an acre of ground divided into rather narrow beds by drainage ditches; these beds allowed for only 2-row plantings. The Betty variety, a semidwarf type of papaya, was used. It was the only dioecious variety that had at the time been sufficiently line-bred to come true from seed. It produces plants approximately 50 percent each of purely pistillate and purely staminate character. By planting 2 plants in a hill, a good stand of bearing plants was attained, with a certain amount of transplanting (about 20 percent) where 2 staminate plants occurred in the same hill. As a certain proportion of staminates were retained (about 1 staminate to 15 pistillates), some of the hills with 2 staminate plants were not disturbed except to remove 1 of the 2 plants. With a variety like Betty, flowering within 2 or 3 months from planting, transplanting of excess pistillate plants can be easily done without severe checking of the growth. With less precocious varieties it would be advisable to plant 3 plants to the hill to decrease to the vanishing point the necessity of transplanting after sex character is shown.

Planting was made so late (beginning June 1, 1936) that no fruits matured that season, so the total yields from the various treatments were taken for the following season from March 1 to November 5, 1937, when the experiment was terminated. The experimental planting was located in a well-protected section of Manatee County, seldom visited by frost. There was no winter injury and growth continued practically throughout the winter of 1936–37, with some fruit ripening in March. The experiment included 3 different spacings (6 by 6 feet, 6 by 9, and 6 by 12); 3 rates of fertilizer applications (low, medium, and high); and 2 frequencies of application (at 15-day and at 30-day intervals). All treatments were duplicated. The number of bearing plants in each plot ranged from 8 to 20, the variation being due to spacing and to the distribution of staminate plants.

With the 3 different spacings, there were thus 6 plots receiving the low, the medium, or the high rate of fertilizer application. Each plot was further divided, one row receiving fertilizer at 15-day intervals and another row at 30-day intervals. The fertilizer mixtures were applied in a circular area around each tree. For the first 2 months all plants received a like amount of fertilizer, 4 ounces per hill at 15-day intervals, using a "seedbed special" (4N–8P–3K) mixture with one-half of the nitrogen from organic sources. After this time differential treatments were started, the low fertilizer plots receiving ¼ pound per hill at 15-day intervals and ½ pound per hill at 30-day intervals; medium plots, double these amounts; and high plots, treble these amounts. The formula, as the plants reached the bearing stage, was changed to 4N–8P–6K, and finally to 4N–8P–8K, with about one-half of the nitrogen from organic sources.

Moisture conditions were good throughout the period of the experiment, and the drainage was at all times adequate. The soil was a medium grade of Norfolk sand with a fair amount of humus. Yields were recorded as to the number of sound fruits harvested and the weight of each fruit.

GROWTH RESPONSES

Differences in growth responses to the several treatments were not marked, although with the highest rate of fertilizer application there was a noticeably more sturdy type of plant. At 11 months from planting, measurements of height (to the terminal bud) and diameter (6 inches from the ground) were taken. These measurements were averaged for the plots receiving different rates of fertilizer applications, and the results are shown in table 1.

TABLE 1.—*Effect of different fertilization rates on height and trunk diameter of Betty papaya trees, 11 months after planting, 1936–37*

Rate of fertilizer application	Height	Trunk diameter
	Feet	*Inches*
Low	5.6	3.8
Medium	5.1	3.7
High	5.8	4.3

When grouped and averaged according to the spacing of plants, regardless of fertilization, there was no marked effect of spacing, except that the closely spaced plants (6 by 6 feet) were slightly more slender, as shown in table 2.

TABLE 2.—*Effect of spacing distances on height and trunk diameter of Betty papaya trees, 11 months after planting, 1936–37*

Spacing	Height	Trunk diameter
	Feet	*Inches*
6 by 6 feet	5.3	3.8
6 by 9 feet	5.2	4.0
6 by 12 feet	5.4	4.0

As a check against soil inequalities, soil samples were taken at the beginning of the experiment and at intervals during its progress. Determinations were made of pH, percentage of organic matter, nitrogen, calcium, phosphorus, and potash (table 3). Fruit samples under different treatments were also analyzed for percentage of water, silica, calcium, phosphorus, potassium, and magnesium, and parts per million of iron, copper, zinc, and manganese (table 4), and for sugars.

TABLE 3.—*Effect of different fertilization rates on physical and chemical properties of the soil*

Rate of fertilizer application	Effective acidity (0–12 inches)	Organic matter	Calcium (CaO)	Phosphorus (P_2O_5)	Potassium (K_2O)	Total nitrogen (N)	Nitrate nitrogen (NO_3)
	pH	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*P. p. m.*
Low	5.07	2.16	0.0890	0.033	0.0062	0.0775	2.33
Medium	4.92	2.06	.0650	.0197	.0065	.073	2.30
High	4.92	2.61	.1012	.0207	.0071	.080	4.08

TABLE 4.—*Effect of fertilization rates on water and mineral content of papaya fruit, August 2, 1937*

Rate of fertilizer application	H_2O	SiO_2	Ca	P	K	Mg	Fe	Cu	Zn	Mn
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*
Low	90.9	0.517	0.1358	0.159	2.549	0.106	58.75	6.21	8.13	5.42
Medium	91.7	.345	.1358	.226	2.546	.109	63.57	5.96	10.42	5.25
High	90.9	.370	.1633	.189	2.204	.109	51.25	6.54	8.76	5.17
Average, all plots	91.2	.411	.1450	.191	2.433	1.08	57.86	6.24	9.10	5.28

At the start of the experiment the soil-acidity tests had shown a fairly close range: pH 4.87 to 5.65 for the first 6 inches of soil; 4.70 to 5.82 for 6 to 12 inches; 4.25 to 5.70 for 12 to 18 inches; 4.25 to 5.15 for 18 to 24 inches. However, in the first 12 inches most of the tests gave a pH fairly close to 5.0. Finely ground limerock (2½ pounds per hill) was applied in preparing the ground before planting, and the final pH tests were all above the 5.0 level, ranging from 5.15 to 6.25 in the topsoil (0 to 6 inches). Although the papaya is apparently fairly tolerant of soil acidity, it seems that a pH of at least 5.0, preferably 6.0 to 7.0, should be maintained.

The percentage of organic matter found was generally low, ranging from 1.24 to 3.35; most of the samples ranged from 2.0 to 2.5 percent at the beginning of the experiment. A year later, the effect of fertilizer applications was apparent in a higher content of organic matter, ranging from 1.72 to 4.11, with most of the samples ranging from 2.5 to 3.5 percent.

The percentages of calcium, phosphorus, and potassium indicated fairly uniform conditions through the area of the experiment, the differences being usually so slight as to be within the range of sampling error. At least such initial differences as may have existed were readily effaced by the amounts of fertilizer supplied, so that the final yield under the various treatments, together with the growth and vigor of the plants, was clearly the result of the plant food supplied rather than of initial soil differences. The results of these initial soil analyses have been grouped according to the series of plots later receiving low, medium, and high applications of fertilizer, and the averages are given herein as a matter of record.

In percentage of total nitrogen the soil samples ranged from 0.060 to 0.090 percent before planting, and from 0.051 to 0.091 percent a year later.

Comparisons of nitrate nitrogen as determined in soil samples taken at the beginning of the experiment (May 13, 1936) and 10 months later (March 18, 1937) showed marked increases especially for the higher rates of fertilization during this period. With an initial average of 2.33 parts per million for the low-fertilizer plots, the amount found 10 months later was 4.48 p. p. m.; the medium-fertilizer plots showed an increase from 2.30 to 6.08 p. p. m.; with the high-fertilizer plots the increase was from 4.08 to 11.51 p. p. m. during the same period. The higher initial average shown by the soil samples from the high-fertilizer plots constitutes an apparent element of experimental error but was traceable to a few samples from one end of a series of plots that had at one time constituted part of a garden. The growth and yields from this small area were not appreciably greater than from other portions of the same plots receiving the high rates of fertilizer application.

Fruit samples (6 ripe fruits) from 18 of the 36 plots were taken at the height of their production (on August 2, 1937) for complete analysis; also, on November 5, 1937, for sugar analysis and comparison of other characteristics.

The sugar analyses made by means of the saccharimeter method, although showing no effects of differential treatments, were interesting in bringing out the fact that the sugar present in the ripe papaya consists almost solely of glucose, only traces of sucrose being found in a few samples. The average percentage of glucose content on a dry basis for the low-fertilizer plots was found to be 9.27 (August) and 8.77 (November); for the medium-fertilizer plots, 9.13 (August) and 8.50 (November); and for the high-fertilizer plots, 9.00 (August) and 8.54 (November). The average for all plot treatments of the August samples was 9.15 percent of glucose and that of the November samples, 8.60 percent.

Table 4 gives the content of the more important minerals, grouped and averaged according to the rate of fertilization, in the fruit samples of August 2, 1937.

Besides these chemical tests, the writers made other tests of the fruit samples from the different treatments, including their physical characteristics (size, weight, shape, etc.) and their fruit quality, including taste, total acidity, and pH of expressed juice. The weights of the November fruit samples, as will be seen from table 5, averaged only slightly more than those of the August samples. There were no consistent differences in size, shape, or weight that might be attributed to the rate of fertilizer applications. The total acidity of the expressed juice was found to be very low, ranging from 0.13 to 0.19 percent, with an average for all samples of 0.16 percent. Likewise, the pH showed a narrow range for the August samples, 5.2 to 5.3; for the November samples, 5.6 to 5.8.

TABLE 5.—*Average weight of August- and November-harvested Betty papaya fruits used for analysis from plots fertilized at different rates*

Date of sampling	Weight of fruit from plot on which rate of fertilizer application was—			
	Low	Medium	High	General average
	Pounds	*Pounds*	*Pounds*	*Pounds*
Aug. 2, 1937	3. 2	2. 8	3. 1	3. 0
Nov. 5, 1937	3. 3	3. 3	3. 2	3. 3

In taste quality there was no detectable difference due to the different rates of fertilizer application. The Betty papaya is predominantly sweet, has a slightly cressy flavor, and is generally excellent in quality, but the fruit is inclined to soften rapidly on reaching maturity. There was no appreciable effect of the differential fertilizer treatments on this tendency to softness. Further experiments are planned with special reference to the effect of fertilizer materials on firmness of fruit.

Effect of Treatments on Total Yields

In table 6 are given the detailed records of yield obtained under the various treatments previously outlined.

It will be seen from the detailed results of the various treatments that in every treatment but one the application of fertilizer at 15-day intervals gave higher yields than the 30-day applications, the advantage being most marked in the close-spaced 6- by 6-foot plots. In these plots the increase by weight, 3,546.2 pounds compared with 2,576.7 pounds (combining the three rates of application), amounted to approximately 38 percent.

Comparison of the plots receiving low, medium, and high rates of fertilizer applications shows little difference in total yield between the low and medium, but a decided increase for the high applications. The combination of close spacing and high fertilization is especially favorable to a high yield with the semidwarf variety used in this experiment. The influence of a high rate of fertilization is especially noticeable in the number of fruits harvested per plant from the different treatments. Combining the 15-day and 30-day applications, the low-fertilizer plots gave an average of 16.9 fruits per bearing plant, the medium-fertilizer 18.2, and the high-fertilizer 26.1.

When the effect of spacing is considered (combining the different rates of fertilizer applications), it appears that there was slightly higher total yield in the 6- by 9-foot plots as compared with the 6- by 12-foot plots (3,842.5 pounds and 3,704.7 pounds, respectively); but with the 6- by 6-foot spacing there was a greatly increased total yield, 6,122.7 pounds, approximately 62 percent greater than the mean yield of the two wider spacings. This increase, of course, is primarily due to the greater number of plants per plot, as the plots were of equal size in all treatments. The number of fruits harvested per plant in the 6- by 6-foot plots averaged 19.3; in the 6- by 9-foot, 19.3; and in the 6- by 12-foot, 23.0.

In applying the results of this experiment to the individual grower's practice it should be noted, as previously pointed out, that the variety used, the Betty, is of semidwarf habit and the results, especially as to spacing, might be quite different with a variety of larger growth habit.

RECOMMENDATIONS FOR GROVE MANAGEMENT

The following statements and recommendations are made on the basis of the experiment just reported and on observations of papaya groves over a period of years. The papaya is easily affected, especially as to fruit quality, by both seasonal and nutritional conditions of growth. Any handicap, such as drought, wind injury, low temperature, or underfeeding, that checks the development of a full crown of healthy leaves is reflected in the poor quality of the fruit. With scanty foliage the synthesis of carbohydrates is reduced, and this results in slower growth and a fruit of disappointing quality. With retarded growth, fruits may develop off or disagreeable flavors quite foreign to the variety when grown under more favorable conditions. It is important, therefore, not only to start with varieties of known merit, but also, as far as possible, to provide optimum growing conditions. It is essential not

Table 6.—*Effect of spacing distances, rate of fertilizer application, and interval between fertilizations on weight and yield of papayas, March 1 to November 5, 1937*

Spacing and interval of fertilizer application	Low-fertilizer plots				Medium-fertilizer plots				High-fertilizer plots				Total	
	Fruits		Weight		Fruits		Weight		Fruits		Weight		Fruits	Weight
	Total	Per plant	Total	Per fruit	Total	Per plant	Total	Per fruit	Total	Per plant	Total	Per fruit		
	Number	*Number*	*Pounds*	*Pounds*	*Number*	*Number*	*Pounds*	*Pounds*	*Number*	*Number*	*Pounds*	*Pounds*	*Number*	*Pounds*
6 by 6 feet:														
15-day	358	18. 8	1, 060	3. 0	370	20. 6	1, 071. 5	2. 9	515	27. 1	1, 414. 7	2. 7	1, 243	3, 546. 2
30-day	240	12. 6	672	2. 8	207	12. 2	606. 0	2. 9	413	23. 0	1, 298. 5	3. 1	860	2, 576. 7
Total													2, 103	6, 122. 7
6 by 9 feet:														
15-day	197	16. 4	590	3. 0	225	20. 5	628	2. 8	245	24. 5	790. 5	3. 2	667	2, 008. 5
30-day	152	12. 7	382	2. 5	234	19. 5	692	3. 0	259	21. 6	760. 0	2. 9	645	1, 834. 0
Total													1, 312	3, 842. 5
6 by 12 feet:														
15-day	260	26. 0	798	3. 0	179	19. 9	538. 5	3. 0	304	30. 4	915. 2	3. 0	743	2, 251. 7
30-day	147	16. 3	319. 5	2. 2	150	18. 8	379. 5	2. 5	247	30. 9	754. 0	3. 1	544	1, 453. 0
Total													1, 287	3, 704. 7
All spacings:														
15-day	815		2, 448. 0		774		2, 238. 0		1, 064		3, 120. 0			
30-day	539		1, 373. 7		591		1, 677. 5		919		2, 812. 5			
Total	1, 354		3, 821. 7		1, 365		3, 915. 5		1, 983		5, 932. 5			

only to choose the proper planting site but also to pay strict attention to timeliness in carrying out the grove operations.

Site, Soils, and Air Drainage

The papaya is a rapid-growing tree and needs at all times readily available plant food to insure thrifty growth and the ability to set and hold its abundant fruit crop. For most economical production, soils of natural fertility, fairly well supplied with organic matter, should be chosen for any commercial papaya planting. Of equal importance with the natural soil fertility is the location with reference to drainage, frost protection, and protection against wind injury. The papaya is so easily injured by standing water at its base or by a water-saturated soil condition that the drainage must be adequate to remove, within a few hours at the most, any excess moisture due to heavy precipitation.

Sites chosen should be known to be reasonably frost-free under normal conditions. Even in such locations provision should usually be made for some method of frost protection. Experience has shown that the papaya seldom will withstand a temperature even slightly below 32° F. without more or less serious injury to the plant and loss of the fruit crop. For advice as to methods of frost protection and information as to frost warnings, growers in the several States are advised to write to the nearest Fruit Frost Center of the United States Weather Bureau. Federal-State stations are at Lakeland, Fla., Brownsville, Tex., and Pomona, Calif.

Windbreaks

For protection against wind injury, advantage may often be taken of row plantings of casuarinas (Australian pines) or hedgerows of oleander, bamboo, or similar shrubby plants. The casuarinas are quick growing and are recommended for border planting around any acreage where it is expected to carry on papaya culture for a term of years. If closely spaced, 5 to 6 feet apart, they will afford considerable protection by the second or third year. In the absence of windbreaks, tall stakes or poles may be set beside the plants and the plants tied to these supports. To avoid injury to the tender stem, the tying should be done with strips of stout cloth, such as burlap or coarse muslin.

Spacing

The proper spacing of papayas in field planting will depend on the variety as well as on soil moisture and fertility. Fairly close spacing affords some protection against wind and cold injury, but for varieties other than those decidedly dwarf in habit, a spacing of 8 by 8 feet is about the minimum that is desirable. Where drainage requires numerous open drain ditches, with the land thus cut up into comparatively narrow strips, such a spacing as 9 by 6 feet may be of advantage, placing two rows on each strip of land between drain furrows. However, the semidwarf variety Betty, as already indicated, produced the highest yields with the closest spacing when spacings of 6 by 6, 6 by 9, and 6 by 12 feet were used in comparative tests. The closely spaced plants also began maturing fruits first and suffered less from sunscald than did the more widely spaced plants. The advantage from close spacing was most marked in plots receiving the highest rate of fertilizer application (1½ pounds per month per plant of the complete fertilizers used in the experiment).

Irrigation

With a shallow-rooted plant like the papaya, a continuous and adequate supply of soil moisture is especially important to act as a solvent and medium for translocation of nutrient material. Even a short period of drought may seriously stunt a growing papaya tree and cause failure in fruit setting. Some system of irrigation should be provided as insurance against failure resulting from short periods of drought even though the rainfall may in ordinary years be amply sufficient for crop production. Where flowing artesian wells are available, as in sections of Florida, the soils are usually adapted to furrow irrigation if the rows are not excessive in length. In these artesian areas a system of subirrigation is often employed for vegetable growing. This system, using open-joint tile, has the advantage of providing also for thorough drainage and might be used to advantage in the papaya plantings (*11*).

In open, porous soils and on land of uneven topography, furrow irrigation is impracticable and the use of portable slip-joint pipe is probably the most economical means of water distribution. A sprinkler system of irrigation has the advantage of requiring little cost for operating labor, and for intensively cultivated small plantings its greater initial cost might well be justified by the ease of operation and the uniformity of water distribution. Local soil conditions and the topography of the land to a large extent will govern the type of irrigation to be employed. Under lower Rio Grande Valley conditions, Friend (*3*) recommends that "irrigation water should be applied sufficiently often to prevent wilting of the plants."

Deficiency of Soil Nutrients

It is now generally recognized that Florida soils may be deficient not only in nitrogen, phosphorus, and potassium, but also in some of the other essential elements required in minute quantities for good plant growth, such as copper, zinc, manganese, and iron. Where such deficiencies exist, they must be made good in fertilizer applications in order to obtain proper development of the papaya tree. Most growers use liberal quantities of stable manure, which seems to make good any such deficiencies on the low hammock soils usually utilized in papaya culture. However, where attempts are made to grow papayas on lighter sandy soils, greater difficulties may be experienced from such deficiencies.

Amount and Grade of Fertilizer and Time of Application

When plants are first set out, an application of a "grower"-type mixture (approximately 5N–6P–5K), with nitrogen derived largely from organic sources, is advisable, applying the fertilizer in circles about the plants and lightly working it in. A few ounces per hill twice a month for the first 6 or 8 weeks should be adequate in most soils. Later the amounts should be gradually increased to 1 to 2 pounds per hill monthly (preferably divided into two applications), and as the fruiting stage is reached the fertilizer used should be of the so-called "fruiter" type (such as 4N–8P–8K). With the advent of cool weather in November or early December when growth practically ceases, fertilizer applications may be omitted entirely, this practice being favorable to fruit ripening. No definite program can be laid down as suited to all soils, and the grower will have to be guided to a considerable extent by the condition of the plant in regulating the amount and kind of fertilizer to be applied. The papaya is a gross feeder but seems to thrive best with fairly frequent applications of relatively small amounts of fertilizer rather than heavy applications at longer intervals.

The plant food requirements of the papaya, under the conditions of the lower Rio Grande Valley, Tex., according to Friend (*3*) are as follows:

> A small quantity of cottonseed meal can be mixed with the soil in the bottom of the hole at the time the seedlings are transplanted to the field, but the hole or spot method of fertilizing is particularly effective. This method consists of making a circle of small punched holes about each plant. None of these holes should be closer than eighteen inches to the trunk of the plant, and six holes should be sufficient. In each hole, which should be about eight inches deep, the fertilizer mixture is applied. This consists of equal parts of ammonium phosphate (11–48–0), cottonseed meal and sulfur; and should be applied at the rate of about one pound per plant. Surface applications of sulphate of ammonia, at the rate of one-fourth pound per plant, should be applied during June and September, when the plants and fruits are developing rapidly.

Cultivation and Mulching

The papaya grove should be kept free from weeds at all times by shallow cultivation, and this is especially important during the dry season from September to June. Some growers have achieved success by mulching with leguminous or other hay, but if this practice is followed it is necessary to surround the grove with a plowed fireguard.

DISEASES

Stevens (*14*) has recently summarized the most important papaya diseases from the standpoint of the papaya grower in Florida and has indicated the most effective means of control. Brief summaries are given here from that source. For more detailed information on the control of papaya diseases, inquiries should be addressed to the Florida Subtropical Experiment Station, Homestead, Fla., Texas Lower Rio Grande Valley Substation, Weslaco, Tex., and the United States Department of Agriculture Horticultural Field Laboratory, Orlando, Fla. According to Friend (*3*), under lower Rio Grande Valley conditions, "papaya plants are susceptible to root rot and one type of wilt. The use of sulfur and acid-forming fertilizers will aid in controlling root rot, but planting on sorghum stubble or clay loam soil is the best means of reducing losses from this disease."

Leaf Blight

Of first importance is papaya leaf blight caused by a fungus *Pucciniopsis caricae* (Speg.) Seaver (*Asperisporium caricae* (Speg.) Maubl.). Papaya leaf blight is easily recognized by the black pustular spots that appear on the under surface of the older mature leaves, young developing leaves being apparently resistant. These spots enlarge by reinfection from spores produced until the entire lower surface of the leaf is affected. Severely affected plants may lose from 50 to 60 percent of their leaves in a period of 2 to 3 months and be so weakened as to be incapable of properly maturing their crop of fruit.

On fruits the black pustular type of spot occurs, similar to those on the under surface of the leaves. The injury to mature fruits is confined chiefly to the marred or spotted surface, and no decay is caused by the fungus. Young fruits are apparently resistant to infection.

Control.—All leaves showing infection should be removed and destroyed. These will usually be the lower and older leaves on the plant. Spraying the under side of the lower leaves with 3–3–50 bordeaux mixture will usually prove effective in controlling this disease if the treatment is started in time and repeated at 2- or 3-week intervals for three or four times. It is not necessary or desirable to spray the upper tender leaves, which may be severely burned by the bordeaux spray. **As bordeaux mixture contains a poisonous substance, users unfamiliar with it should get technical advice, as recommended on page 30.** Leaf blight is most apt to give trouble through the winter season, and a close watch should be kept for it in the late fall.

Powdery Mildew

Powdery mildew, caused by a species of *Oidium*, is also a cool-weather disease and attacks chiefly the mature leaves of the plant. It is more rapid in its action than leaf blight and if unchecked may soon cause the leaves to turn brown, die, and drop. It may also give trouble on young seedling plants in the seedbed. As the name indicates, the affected leaves gradually become covered with a white powdery growth of fungus hyphae and spores, starting from roundish spots half an inch or so in diameter, greenish yellow in outline, with a brownish central portion. No definite cases of mildew have yet been observed on papaya fruit in Florida, nor does it attack the bloom or immature leaves.

Control.—Severely affected leaves should be removed and destroyed. Two or three applications of good dusting sulfur should control any ordinary attack, but dusting should start as soon as any mildew appears. The disease appears to be spread by wind and insects and requires cool moist conditions for its most destructive work. **As sulfur is irritating, operators of dusting machines should protect their eyes and respiratory passages.**

Fruit Rot

Anthracnose, or fruit rot, caused by a species of *Colletotrichum*, is the most common cause of fruit decay in Florida. The disease appears as sunken spots or pits on the surface of the ripe fruit, varying from ¼ to 1 inch or more in diameter, the centers of which soon become black. The flesh beneath these spots becomes soft and watery, and the decay will gradually penetrate into the interior, rendering the fruits worthless. Frequently the decay will make its appearance around the stem end of the fruit. Fruits that are allowed to remain on the plant until fully ripe and beginning to soften become infected more readily than those that are picked by the latex test (see p. 14) and allowed to soften after picking. No satisfactory method of treating picked fruit to prevent this type of decay has yet been found.

Control.—All dead leaves, leaf stems, and infected fruits should be removed from the vicinity of bearing plants. Fruits should be picked when showing maturity according to the latex test and should not be allowed to ripen fully on the plant.

Damping-Off

Damping-off of papaya seedlings, caused by a species of *Rhizoctonia*, is a disease confined chiefly to the seedbed or occasionally to plants recently transplanted. The stem of the plant usually at or just below the surface of the soil is penetrated by this soil-inhabiting fungus, and the tissues are so weakened that the plant falls to the ground and soon decays. Very little can be done in the way of control after the disease appears in a seedbed. Excessive moisture with a waterlogged condition of the soil favors a rapid spread of the fungus.

Control.—The most effective prevention of loss from damping-off in seedbeds is through the use of sterilized soil. Where practical, steam is the most effective sterilizing agent. Small lots of steam-sterilized soil may often be purchased from commercial nurseries equipped with steam sterilizers. Soil sterilization by steam is also a safeguard against seedbed infestation by nematodes that cause root knot. Formaldehyde treatment probably offers the next best alternative as a protection against damping-off. Commercial 40-percent formaldehyde (formalin) should be diluted to 1 part in 50 of water before using; 1 to 1½ gallons of the diluted solution should be applied with an ordinary sprinkling can to each square foot of surface soil to be treated. The treated area should be covered with canvas or heavy paper for at least 12 hours after treatment. Later the treated soil should be aerated by occasional turning, and the seeds should not be planted until 2 weeks after the treatment. **As some people are more sensitive than others to the irritating fumes of formaldehyde, users unfamiliar with it should get technical advice, as recommended on page 30.**

INSECTS[5]

For more detailed information on the control of insect pests of the papaya, inquiries should be addressed to the Florida Agricultural Experiment Station, Gainesville, Fla., or to the United States Department of Agriculture Insect Laboratory, St. Lucie, Fla.

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[5] Prepared by Herbert Spencer, entomologist, in charge of laboratory (St. Lucie, Fla.), Division of Fruit Insect Investigations, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture.

PAPAYA FRUITFLY

The papaya fruitfly (*Toxotrypana curvicauda* Gerst.), somewhat resembling the common brown wasp, has at times proved a discouraging factor in developing a papaya-growing industry. The larvae (commonly called maggots) of this insect developing from eggs laid in the seed cavity of immature or ripening fruits cause the fruits to be useless for consumption. The insect breeds extensively in "wild" or volunteer papayas, and all such plants should be destroyed in papaya-growing areas. Fruits when nearly full grown are sometimes badly scarred by the attempts of the fruitfly to lay eggs in such green fruits, even though many of these eggs do not produce live larvae, being digested or killed by the latex present in the green fruits. All fruits decaying from whatever cause should be removed twice a week and destroyed to prevent possible infestation with the papaya fruitfly (*6*). This fruitfly breeds only in the papaya. A period of 60 days with no host fruits available for egg laying is usually ample for the eradication of papaya fruitflies in the vicinity. In many situations protection may be obtained by the use of cheesecloth or mosquito netting. Entire trees may be covered with the material, or individual fruits covered with bags; in either case the flies will not try to sting the fruits (*8*).

PAPAYA WHITE FLY

The papaya white fly (*Trialeurodes variabilis* (Quaint.)) at times may prove a serious pest. Infestation by this insect breeding on the under side of the leaves may be overlooked until sooty mold begins to appear. This sooty mold is due to the growth of a fungus in the honeydew secreted by the white fly. The use of standard sprays, such as oil emulsion, for the control of this insect pest is attended with considerable risk, because of the fact that the papaya foliage is easily injured by oil sprays. Growers contemplating the use of such sprays should follow the directions given by the State agricultural experiment station.

WORMS

Hornworms (previously referred to as the larvae of a sphinx moth) may do severe damage at times by eating the foliage. Hand removal during frequent inspections is usually an effective means of control. In large plantings it may be necessary to resort to spraying with lead arsenate. Another worm, the corn earworm (*Heliothis armigera* (Hbn.)), does injury by feeding on the fruit stems and causing fruits to drop prematurely. Their occurrence among the fruits is usually indicated by the presence of numerous casts, the worm hiding behind the fruits. Hand removal, with a slender brush or bundle of feathers, is the most effective means of control. Dipping the brush in bordeaux spray to which lead arsenate has been added affords a measure of protection against reinfestation, the fruit stems being coated with this mixture. This treatment may also be used as a preventive. **As lead arsenate sprays are poisonous, users should handle them with care and get technical advice from State or Federal agencies, as recommended on page 30.**

NEMATODES

Soil used for seedbeds should be absolutely free from the nematode that causes root knot. Heat sterilization is the most dependable treatment for this purpose (see p. 32).

A careful selection of land in order to avoid that with previous root knot nematode infestation is essential and may often avert severe losses from this pest. Old cultivated fields that have grown nematode-susceptible crops, such as tomatoes, peppers, squash, bean, grapes, or figs, are generally unsuited to papaya growing, and land containing nematode egg masses in undecayed roots cannot adequately be freed of root knot by chemical means. However, if plants are started free of these nematodes and are kept well fertilized and watered, they may succeed in lightly infested land because nematode injury is mainly of the nature of a starving process. As heavily invaded roots are incapable of transporting normal amounts of water and food materials, poorly nourished plants succumb much more readily than do plants properly cared for. The ability to produce new root growth rapidly is important in withstanding nematode attack, but this process is frequently a serious drain on the vitality of the plant, and thus root knot insidiously becomes a limiting factor in profitable production. Susceptible cover crops should not be used in groves, because they provide an enormous increase in the soil population of the root knot nematodes; *Crotalaria spectabilis*, being immune, is recommended as the best cover crop.

It is usually impracticable to treat with chemicals the entire area for field planting, but spaces of at least 1 square yard where the papaya plants are later to be set may be treated. Some method of mulching these treated spots, as with square covers of heavy paper, should be employed to obviate the need for cultivation, which would cause reinfestation of the treated areas by nematodes from adjacent soil. The best chemical nematocide used at present is tear gas or chloropicrin; in sandy soil an application of 200 pounds to the acre, used in the planting spots, is recommended. This treatment should be made in moderately moist soil, best if the soil when balled by hand just keeps its form. The soil temperature should be above 60° F. A special injector set to deliver 1.5 or 2 cc. of chloropicrin in holes 6 to 10 inches deep, 10 to 14 inches apart, in staggered rows is recommended as the most practical means of application. **Users of chloropicrin should protect their hands, eyes, and respiratory passages.** The effectiveness of this treatment is greatly increased by sprinkling the soil surface immediately to produce a moisture seal that reduces the escape of the fumes; rain succeeding the treatment or a covering with glue-coated wrapping paper will have the same effect. Calcium cyanamide has been recommended for nematode control in sandy soils, but its value is now known to be largely that of a fertilizer rather than of a nematocide. The user of the chemicals mentioned should consult technical experts as recommended on page 30 and should follow closely their directions as to dosage and method of application.

For more detailed information on prevention or control of root knot in particular situations, inquiries should be directed to the Florida

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[6] Prepared by G. Steiner, principal nematologist, Division of Nematology, Bureau of Plant Industry, U. S. Department of Agriculture.

Agricultural Experiment Station, Gainesville, Fla., to the grower's State agricultural experiment station, or to the Division of Nematology, Bureau of Plant Industry, United States Department of Agriculture, Beltsville, Md.

SUMMARY AND CONCLUSIONS

Papaya culture in the subtropical portions of the United States is handicapped by certain hazards that must be carefully considered by any prospective grower.

First among these hazards is injury from cold, a temperature of 32° F. being near the low limit for this tender plant. Even where provision is made for frost protection, the site selected should be one known to be free from freezing temperatures in normal seasons. As there are few places in the continental United States where such temperatures are not occasionally experienced, some method of protection against cold damage must usually be provided.

Drainage is also vitally important in bringing a papaya planting to successful fruiting. The drainage provided must be adequate to prevent the standing of surface water for even a few hours around the base of a papaya plant.

Protection against strong winds is essential in most locations. The use of windbreaks of such plants as casuarinas, oleanders, or bamboos, or the interplanting of similar protective plants is advisable. Where such protection is not available, the use of tall stakes or poles to which the papaya trees are securely tied may be resorted to.

Soils that are presumably free from nematodes should be chosen for planting.

Provision for irrigation should be made in nearly all cases, as the papaya is easily injured by short periods of drought and fails to set a crop under such conditions.

Papaya trees with good root systems may be rejuvenated by the practice of cutting back old plants and forcing a new sprout from near the base of the stem.

Fertilization should be liberal in amount, frequent light applications being preferable to heavy applications at longer intervals.

Sanitary precautions should be taken or other control measures followed to prevent damage from diseases and insect pests.

The papaya grower who has secured a satisfactory or superior variety should maintain that variety by the inbreeding or the self-pollination procedure outlined in this circular. Until superior varieties of substantial uniformity are more generally available, papaya culture as an industry cannot be established on a sound horticultural basis.

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